

Annual Summary Report

This report covers the period of December 15, 2014 to December 14, 2015

Submitted to

The Office of Naval Research

Project Title: Noise of High-Performance Aircraft at Afterburner

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This is an annual summary report requested by the Office of Naval Research, Naval Air Warfare and Weapons Department (Code 35). This is sent to you in lieu of the regular quarterly progress report.

Section I: Project Summary

1. Overview of Project

Abstract:

Until recently, the noise of high performance military aircraft has not been studied in details. During the last two years, noise spectral data from the Navy F18E and the Air Force F22 aircraft became available to the principal investigator. The present project is to analyze these data to identify any major differences between the dominant noise components of these jets and those of a standard high temperature laboratory supersonic jet. It is also a goal of this project to investigate the noise generation mechanisms of any new dominant noise components identified in the present study. At the end of the first year of this project (2015), we were able to clearly identify two new dominant noise components from the F22 at afterburner operating condition. Our investigation indicates that these two new noise components could be produced by the fast and slow waves of indirect combustion noise. For the F18E aircraft, we find that its noise, at high engine power settings, also includes new noise components in addition to the usual fine scale turbulence and large turbulence structures noise of laboratory supersonic jets. Furthermore, in addition to jet noise, fan noise is also found to be a dominant component. That fan noise can be identified in F18E noise spectra is totally unexpected. It has been widely assumed that jet noise is so dominant that it completely overwhelms and buries fan noise. A second objective of this project is to investigate the generation of indirect combustion noise in a military styled nozzle. Indirect combustion noise is considered to be possibly an important noise component when the aircraft is operating at afterburner condition.

Objective:

This project has three primary objectives. They are:

- i. Analyze the noise data from the F18E and F22 aircraft. Compare the noise spectra with those of laboratory hot supersonic jets.
- ii. Identify any new dominant noise components emitted by military high performance jets. Investigate the generation mechanisms of these new noise components.
- iii. Investigate the generation of indirect combustion noise in a military styled nozzle when the engine is operating at afterburner condition.

Introduction:

On the flight deck of an aircraft carrier, navy personnel work in close proximity to high performance jets at takeoffs and landings. The noise level emitted by these jets is

intense. It is known that there are serious hearing loss issues. This project is to investigate the source of noise and the noise generation mechanisms. The aim is to use the basic knowledge gained in this project to see if it is possible to develop effective noise suppression schemes or devices.

Background:

The noise of high-speed jets has been studied for many years in various universities, government and industrial laboratories. At the present time, there has accumulated a good deal of understanding of the dominant noise components of these jets and their generation mechanisms. For hot supersonic jets, there are two dominant noise components. One is from the fine scale turbulence and the other is from the large turbulence structures of the jet flow. Prior to this project, the principal investigator and his coworkers were the first to establish that each of these two noise components had a distinct characteristic spectral shape. The spectral shape is independent of jet Mach number and jet temperature. In the literature, these characteristic spectra are referred to as similarity spectra. In the present project, these two similarity spectra are used to identify the noise emitted from both the fine scale turbulence and the large turbulence structures in the jet plume of the F18E and F22 aircraft. It has been proven that by carefully fitting the two similarity spectra to the measured spectra of the F18E and F22 aircraft, a clear identification of new noise components is possible.

Recently, it has been suggested that at afterburner operating condition, military jets do produce significant level of indirect combustion noise. To investigate the processes by which indirect combustion noise is generated inside a military styled nozzles, high quality numerical simulations are used. Indirect combustion noise is generated when hot and cold spots from the engine combustor are convected past the non-uniform mean flow in the nozzle of the engine. This process is stochastic, since the hot and cold spots are randomly distributed both in space and time. To perform this type of simulation, first, it is necessary to develop a stochastic boundary condition that generates a field of randomly spaced hot and cold spots as input to the computation. The field of hot and cold blobs is characterized by a specified intensity and a spectrum of temperature fluctuations together with a characteristic size of the blobs. Development of such a stochastic numerical boundary condition is part of the research work of 2015 and has now been completed. Numerical simulations are to be performed in 2016.

2. Activities and Accomplishments

Since the F18E aircraft is more relevant to NAVAIR, we will concentrate reporting our work for this aircraft. The work for F22 aircraft has been published in the Journal of Sound and Vibration. Because of space limitation, interested readers are referred to the published article.

F18E, generally, operates at three power levels in addition to the idle setting. The lowest power is labeled as 80N2. The next is military power, labeled as Mil. The highest power is at afterburner and is labeled as MaxAB.

We are able to establish that at low power the jet noise of F18E is essentially similar to those of a high-speed laboratory jet. A laboratory jet radiates two dominant noise components. Fig. 1 shows the two noise components of a laboratory jet. Radiated to the sideline and in the upstream direction is the fine scale turbulence with a broad spectrum. Radiated to the downstream direction, in the form of Mach waves, is the large turbulence structures noise. This noise component is confined to a Mach cone with a more narrow and peaky spectrum.

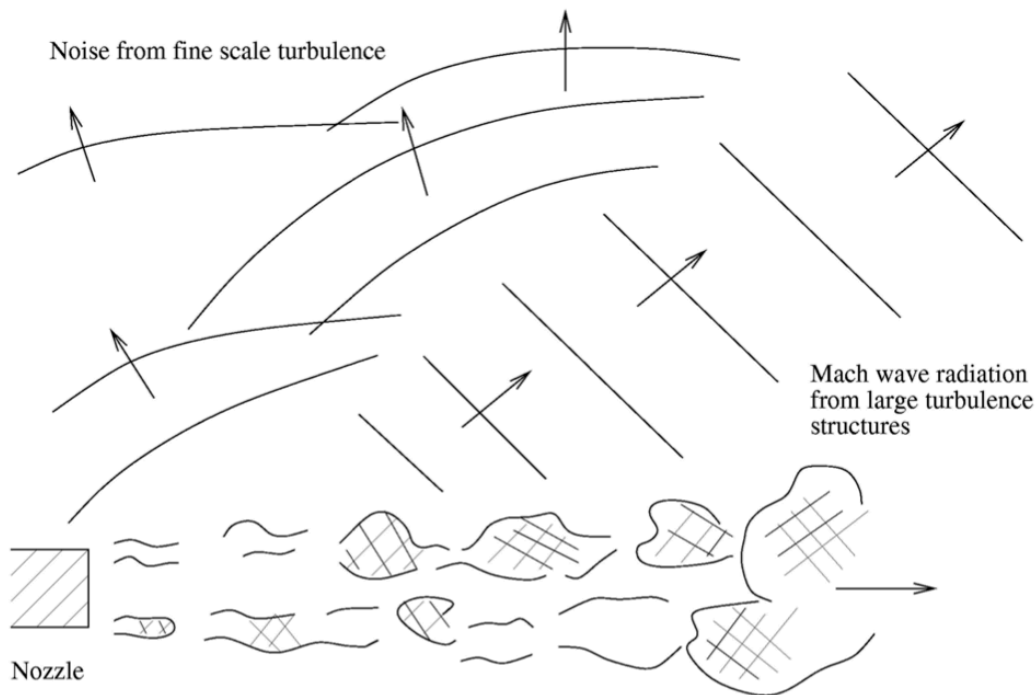


Figure 1. The two dominant noise components of a high-speed laboratory jet.

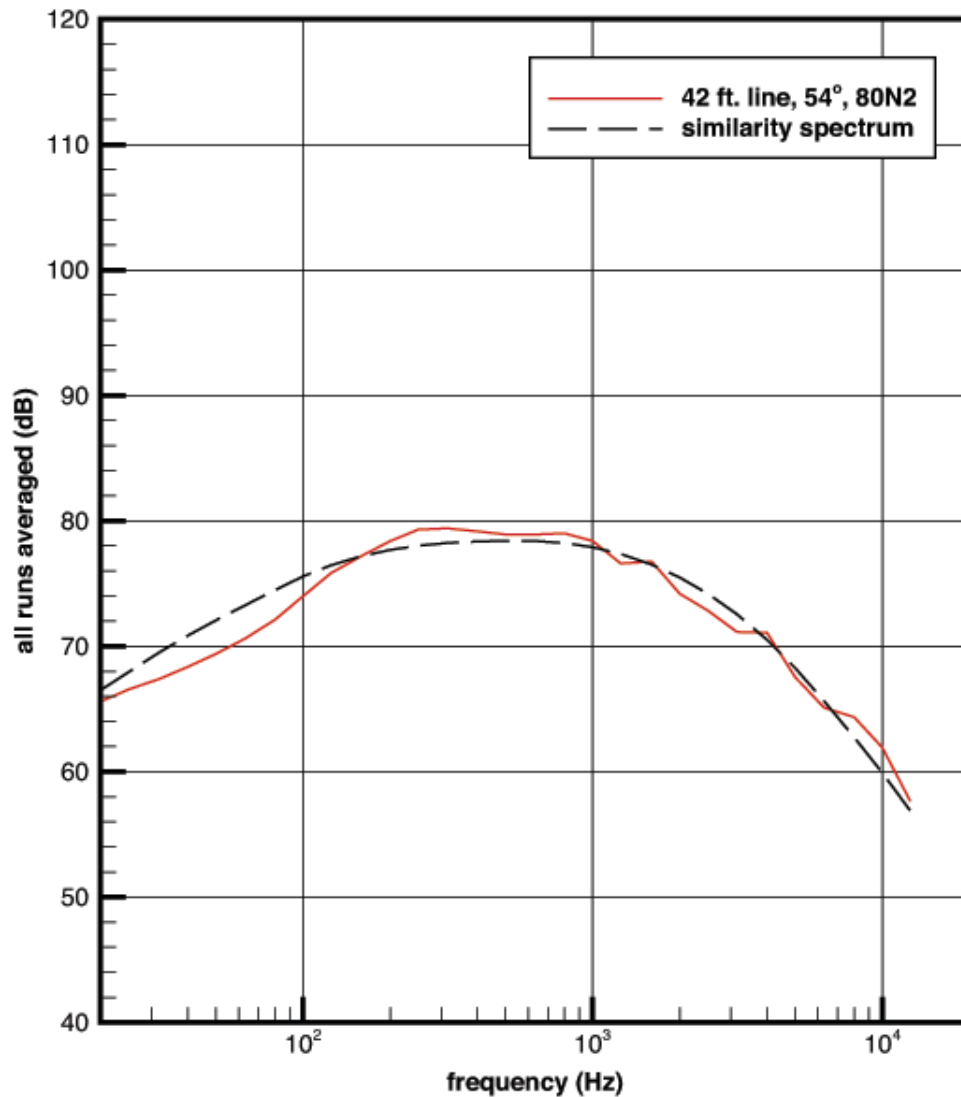


Figure 2. Noise spectrum at 65° inlet angle at 80N2 power setting.

Figure 2 shows the measured noise spectrum at 54° inlet angle. Also shown in dotted line in this figure is the similarity spectrum of fine scale turbulence noise. It is clear that the two spectra are nearly the same. Similarly, good agreements are found for other sideline and forward directions. In the downstream direction, the measured noise spectral shapes are in good agreements with that of the large turbulence noise spectrum. Figure 3 shows how good the two spectra match each other. Based on the good spectral comparison, we conclude that at low power, the noise of F18E has the same two dominant noise components as those of high-speed laboratory jets.

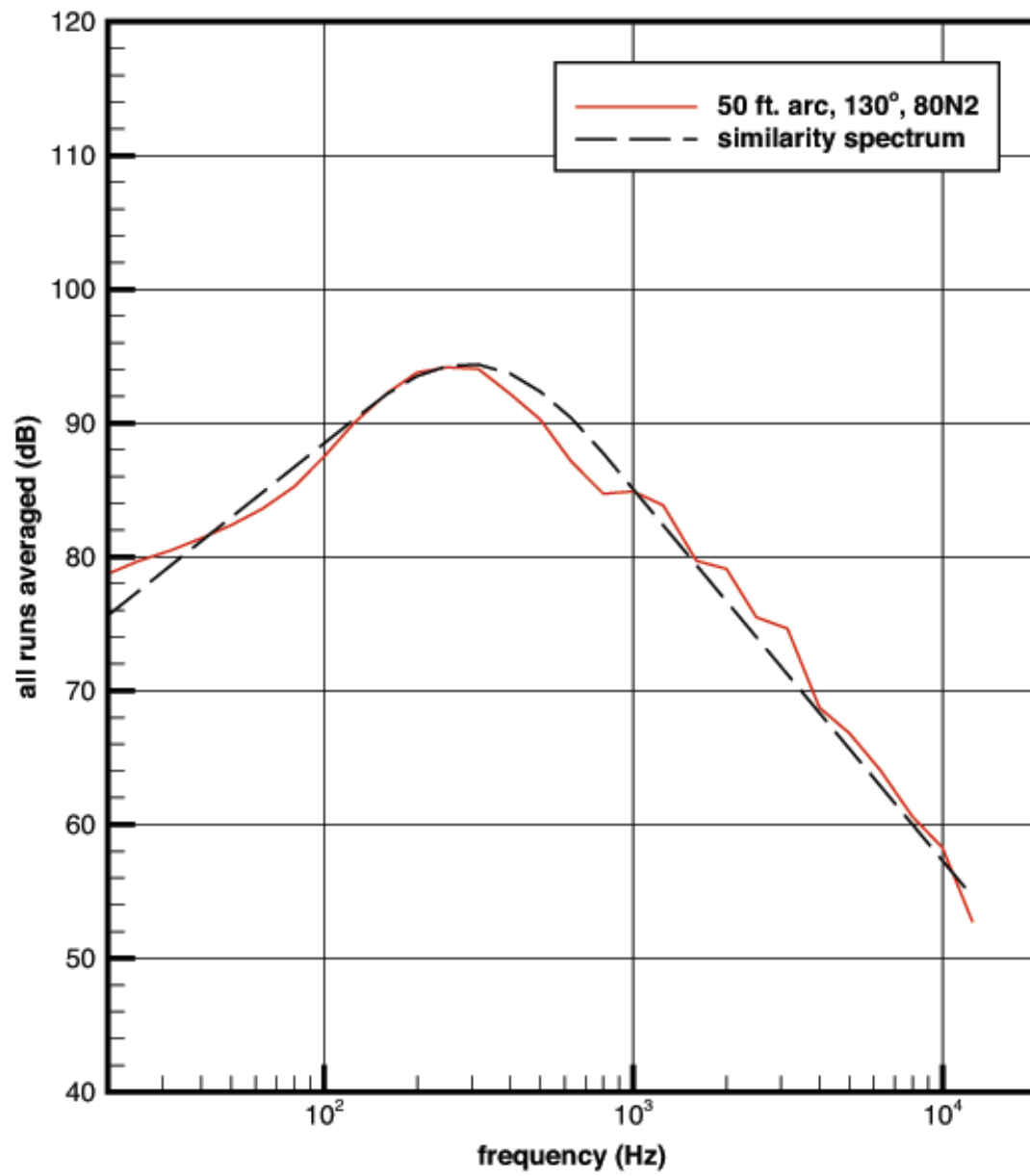


Figure 3. Noise spectrum at 130° at 80N2 power setting.

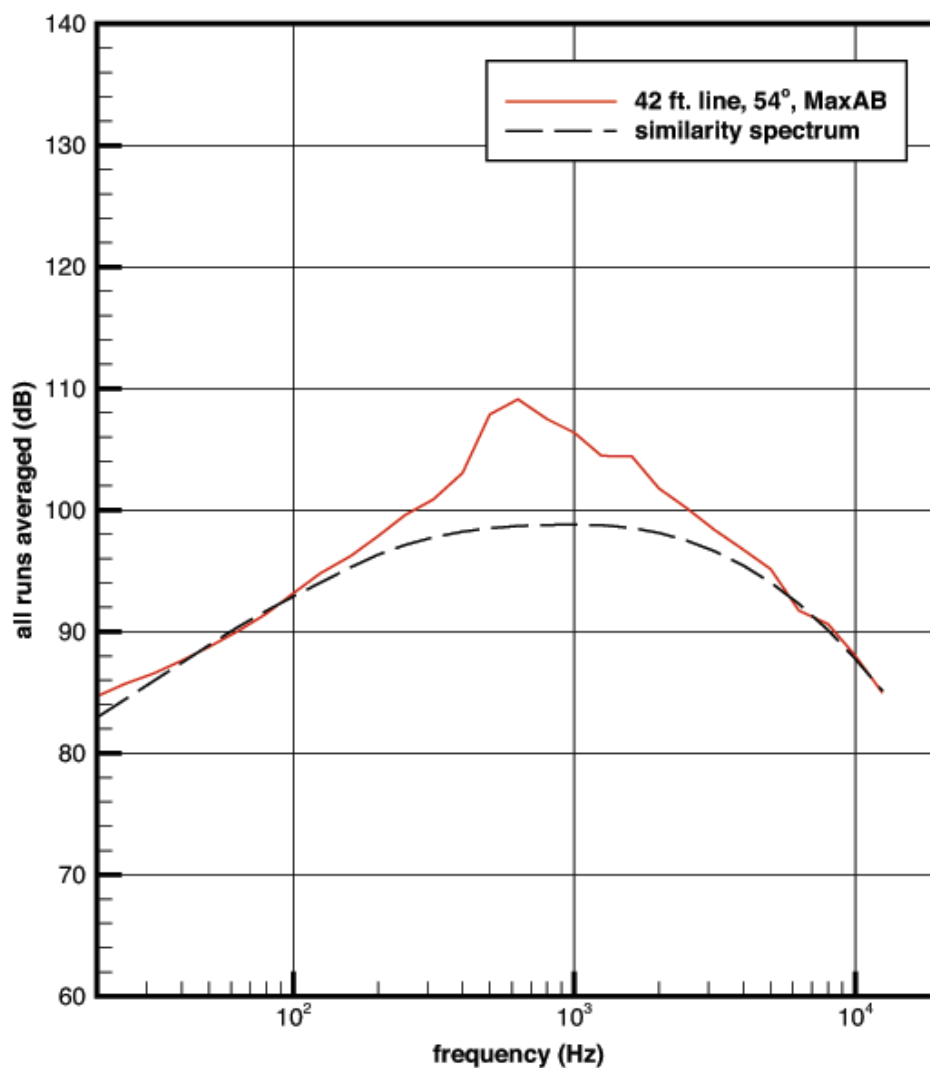


Figure 4. Noise spectrum at 54° at MaxAB power.

At higher operating power, Mil and MaxAB, the noise of F18E is found to differ from those of laboratory jets. Figure 4 shows the measured spectrum at 54° at MaxAB. The dotted curve in this figure is the similarity spectrum of fine scale turbulence noise. What this figure indicated is that at MaxAB power, the noise radiated in the sideline and upstream direction has an extra more dominant component in addition to the fine scale turbulence noise. This is also true for noise at Mil power.

In the downstream direction, there is strong evidence that the jet noise of F18E consists of not just the large turbulence structures noise as for a laboratory jet but there is an additional noise component. Figure 5 shows the combined noise spectra at MaxAB for inlet angles 125° to 160°. The spectra exhibit two distinct peaks. The high frequency peak

is the large turbulence structures noise. The low frequency peak appears to be a new noise component that has not been identified before.

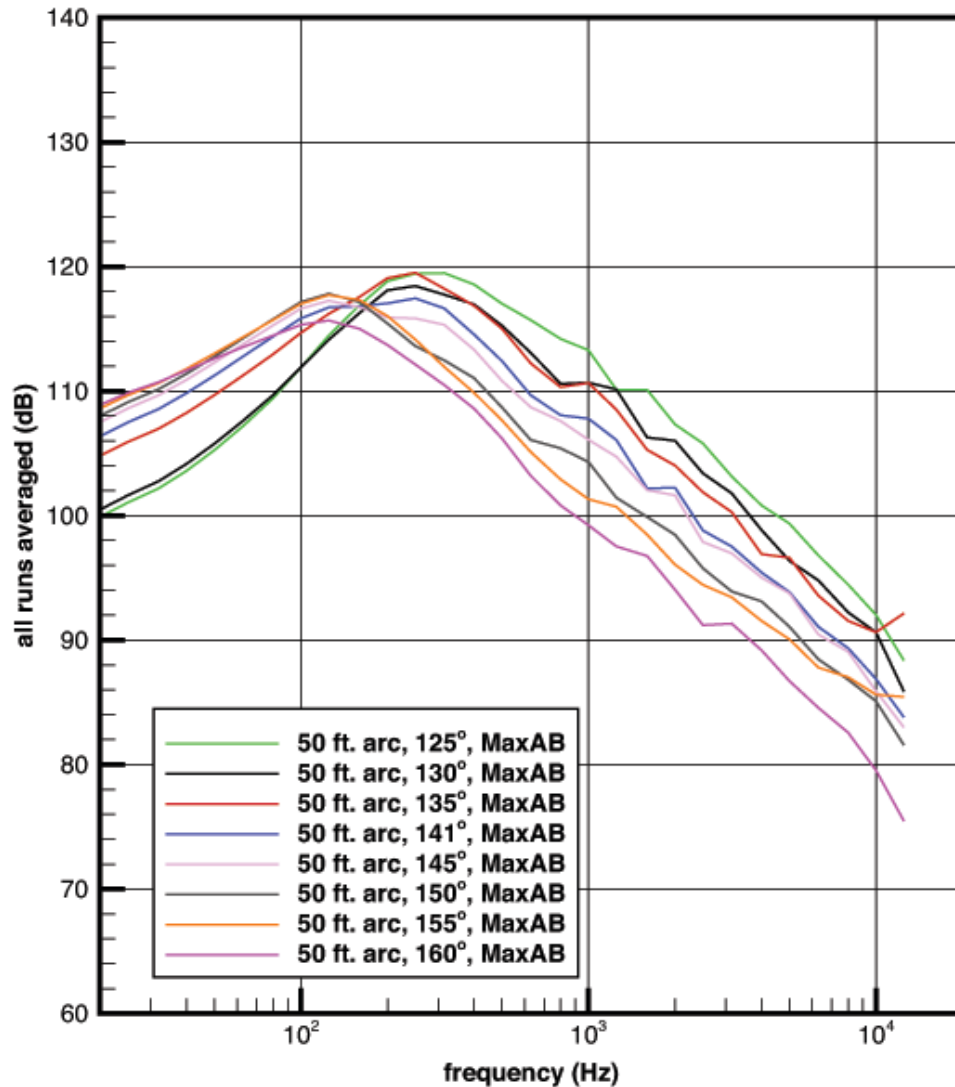


Figure 5. Noise spectra at MaxAB power at angle 120° to 160° showing two independent peaks.

It has traditionally been assumed that at high jet velocity and temperature high performance military aircraft noise is dominated by jet noise alone. Fan noise is not considered to be dominant. In the case of F18E aircraft, this turns out to be not true even though it is the case for the F22 aircraft. For the noise of F18E, fan noise is dominant at high frequencies. It is not buried underneath the jet noise spectrum. Figure 6 shows the noise spectrum at 135° angle. The similarity spectrum of large turbulence structures noise

is a good fit to the jet noise of this aircraft. However, at frequency above 1 kHz, fan noise dominates. This result invalidates the traditional thinking and assumption.

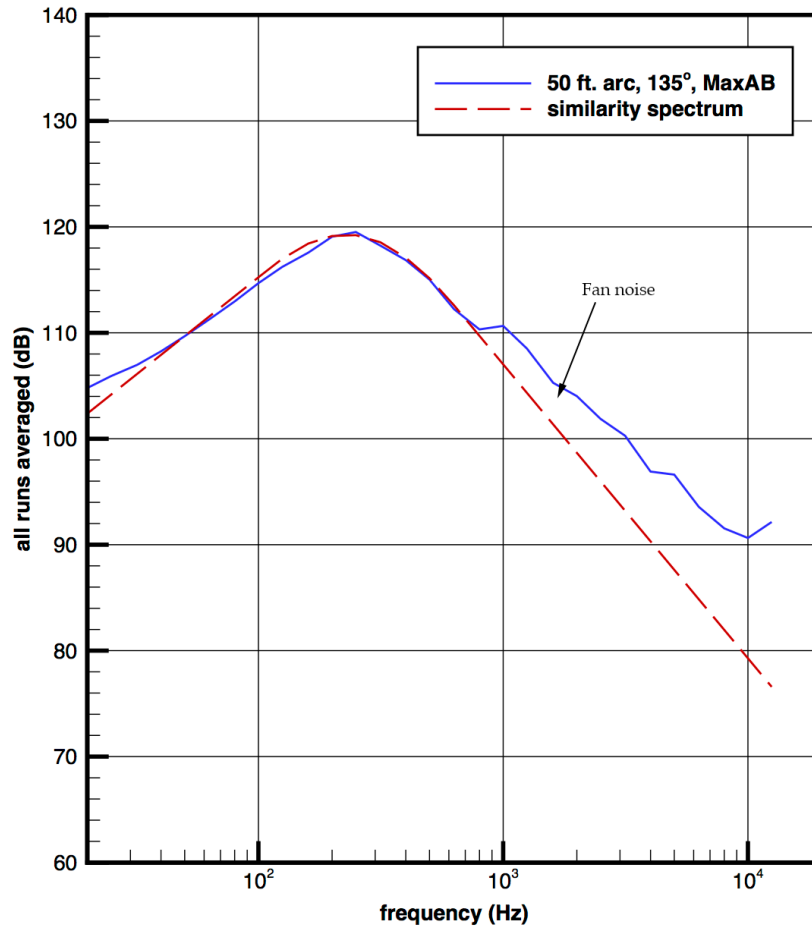


Figure 6. Noise spectrum at 135° at MaxAB power. Dotted curve is the similarity spectr

We have also completed the development of a stochastic boundary condition to be used in the indirect combustion noise simulation work. The simulation work will be carried out in the second year (2016). Space limitation does not allow a detailed presentation of the stochastic boundary condition here. The results will be reported in the next quarterly progress report.

3. Findings and Conclusions

The significant findings of our first year (2015) research are:

- i. We are able to show that at low power operating condition (80N2), the jet noise of F18E aircraft has the same dominant components as a standard high-speed laboratory jet.
- ii. At high power settings (Mil, MaxAB) the jet noise of F18E aircraft has additional new dominant components. The origin and generation mechanisms of these new components have yet to be investigated and determined.
- iii. It has been traditionally assumed that for high performance military aircraft, jet noise completely dominates the entire noise spectrum. Fan and other noise components are less intense so that they are not expected to be observable in measured spectrum. In other words, they are buried underneath jet noise. However, we have now found clear evidence that this generally accepted assumption is incorrect. For F18E aircraft, Fan noise dominates the high frequency part of the noise spectra that are radiated in the downstream direction.
- iv. As far as is known, noise measurement standard for military high performance aircraft calls for 1/3 octave band measurements using pole microphones. Our data analysis reveals that the present standard has two major deficiencies. We would like to recommend amendments to the standard to include the measurement of narrow band data and the use of ground microphones. We intend to make these recommendations to NAVAIR and the Air Force.

4. Plans and Upcoming Events

The following activities are planned or in the planning stage.

- i. Complete narrow band data analysis of the noise of F18E. Specifically, cross-correlation and cross-spectra will be computed and analyzed to look for a possible “beaming” phenomenon especially when the aircraft is at high power setting.
- ii. Secure noise data of F35A & B. If ground microphone data becomes available, perform (for the first time) a spectral data analysis. Comparison of the noise characteristics of the three major military aircraft (F18E, F22 and F35A & B) will also be made.
- iii. Discuss and team-up with NAVAIR personnel the possibility of hosting a special session on “the noise of high performance military aircraft” at the 2017 AIAA Aeroacoustics Conference or a similar Gas Turbine Conference.

- iv. Perform, for the first time, direct numerical simulation of the generation of indirect combustion noise inside military styled nozzles. This effort is to assess the importance of combustion noise as a component of military aircraft noise.

Milestones

2016	1 st quarter	2 nd quarter	3 rd quarter	4 th quarter
Analysis of F18E narrow band noise data	_____			
Analysis of F35A & B 1/3 octave band noise data		_____	_____	
Numerical simulation of the generation of indirect combustion noise in military styled nozzles	_____	_____	_____	_____
Prepare and submit final report				—

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